Patterns of phytoplankton productivity in two morphologically different oxbow lakes in the Black Warrior River drainage in Alabama, U.S.A.

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ABSTRACT
Many different types of oxbow lakes, created by river meandering, exist in the drainage of the Black Warrior River. Phytoplankton productivity and spatial distribution of productivity using the ^{14}C method were studied in two morphologically different oxbow lakes. Touson Lake is a typical oxbow lake type in the region with steep basin morphometry, length (l): 1.2 km, maximum depth (Z_m): 6.7 m. Cypress Pond has shallow depth and well-developed submersed aquatic plants, l: 2.25 km, Z_m: 2.2 m. Daily production at Touson Lake ranged from 43 to 550 $mgC/m^2/day$ (mean: 258, n=6), while Cypress Pond showed somewhat lower productivities (range: 16 to 256 $mgC/m^2/day$, mean: 88, n=4). In highly turbid Touson Lake, highest productivities usually occurred at the surface. In Cypress Pond productivity, which was inhibited at the surface by light, was highest at the 0.5 m depth. Spatial distribution of productivity at Touson Lake was not variable among the 5 sites (19.86 $\pm$ 6.6 $mgC/m^3/h$, n=5). However, highly variable distributions of productivity occurred in Cypress Pond (16.51 $\pm$19.1 $mgC/m^3/h$, n=6). This variability was partly supported by fluctuating underwater light conditions caused by the distribution of submersed aquatic plants. Based on phytoplankton productivity, Touson Lake and Cypress Pond appear to belong to the mesotrophic and oligotrophic lake categories, respectively.
Keywords: oxbow lake, morphometry, water chemistry, primary production, phytoplankton.

INTRODUCTION

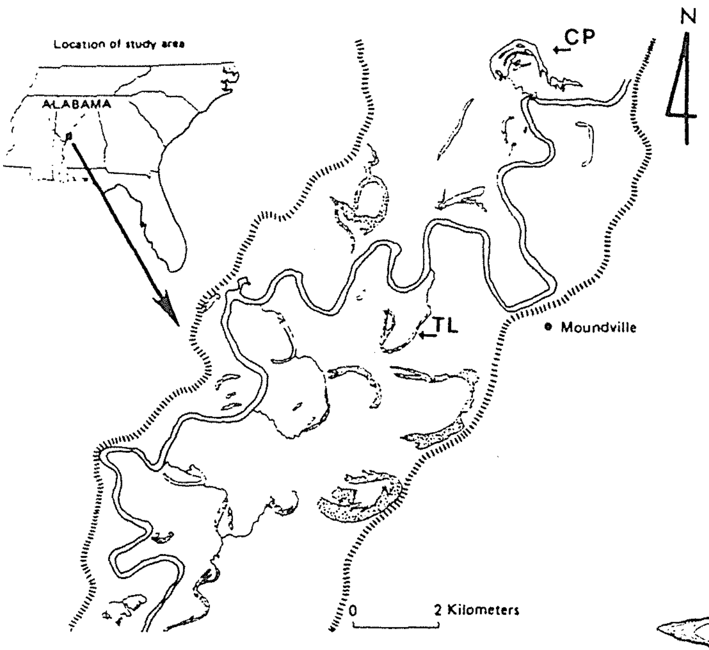
Floodplain lakes are common around rivers throughout the world and they are recognized as productive features of floodplain landscapes. Morphometry of floodplain lakes is quite diverse and is possibly an important factor in controlling trophic status (3). However, these lakes have received little attention from limnologists compared to lakes of other origins.

Only recently has metabolism of floodplain lakes been studied throughout the major rivers of world. However, few studies have addressed the factors affecting the metabolism of these lakes. Several studies of tropical floodplain lakes (such as lakes along the central Amazon River and Paraná River) indicated that morphometric features of lakes such as the distance from the river, maximum depth, and orientation of the lake possibly play an important role in lake metabolism (2, 5, 7).

Some floodplain lakes within the Black Warrior River drainage system in the southeastern U.S. are very shallow with abundant aquatic macrophytes within the basin. Others maintain steep sideslopes around the periphery of the basin, where extensive development of cypress trees occurs, but few macrophytes develop (4). We were interested in comparing physico-chemical features of the lakewaters in these two types of lake systems as well as general patterns of primary productivity and phytoplankton composition. In particular we were interested in investigating the effects of the different kinds of higher plant vegetation on the spatial variability of phytoplankton productivity within the lake. Although both types of higher plant vegetation can produce a shading effect on the phytoplankton, we hypothesized that the lake with abundant aquatic macrophytes would have more spatially variable phytoplankton productivity.

Site description

The Black Warrior River originates in the Appalachian Plateau of north central Alabama and has a total drainage of 16,254 km^2 and 279 km of river length (8). As the river enters the northern part of the Coastal Plain near Tuscaloosa (87° 31'W, 33° 00'N) the floodplain widens and contains a series of oxbow lakes (Fig. 1).



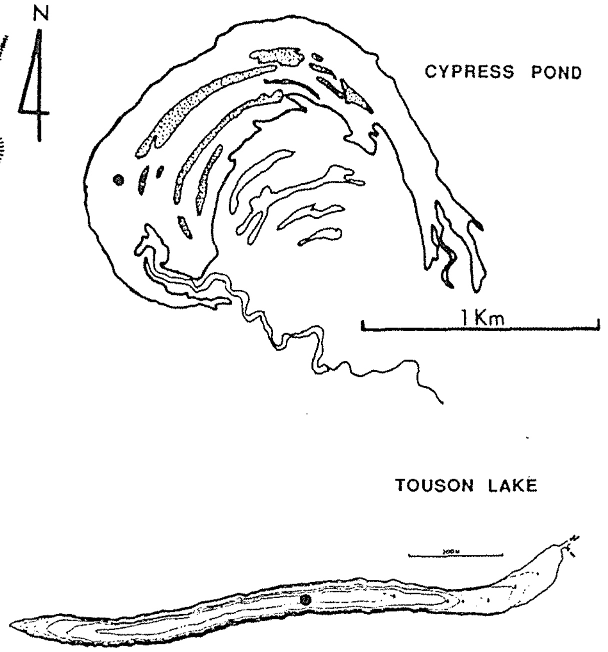


Fig. 1 (left). Study area showing different water bodies within the Black Warrior River floodplain (CP: Cypress Pond, TL: Touson Lake). Stippled areas indicate swamp region.

Fig. 2 (right). Detailed map of Cypress Pond and Touson Lake. Stippled areas at Cypress Pond indicate emergent vegetation. Contour intervals at Touson Lake are 1 m.

Since these lakes are in different stages of development, the size and shape of these lakes are highly variable.

Two lakes with contrasting morphometries, Touson Lake and Cypress Pond, were selected for the limnological studies (Fig. 2). Half of the original lake of Touson Lake has been filled in, and the entire shore of the lake is surrounded by cypress trees (Taxodium distichum). Touson Lake is deeper than Cypress Pond, and no submersed aquatic macrophytes are found (maximum depth: 6.7 m, mean depth: 2.6 m). Cypress Pond still retains a U-shape, but is very shallow (maximum depth: <2.5 m). Emergent and floating macrophytes are prolific in the shallow regions (less than 1.5 m deep: Typha latifolia, Nelumbo lutea, and Nymphaea odorata). In the deeper areas (depth >1.5 m), patches of submersed macrophytes (Potomogeton foliosus, Ceratophyllum exalbescens, and Najas guadalupensis) are common.

Unlike Touson Lake, cypress trees at Cypress Pond are found in the middle of the lake, and the age of the cypress seems to be relatively young (<200 years). Cypress trees at Touson Lake are older (>500 years) (3). While Touson Lake showed a minimal disturbance from human activity, Cypress Pond has experienced significant alteration. Approximately 50 years ago, a small dam was constructed to hold water in the pond. Currently, water levels at Cypress Pond remain constant under normal conditions, i.e., non-flooding periods.

MATERIALS AND METHODS

Physical features (light intensity and temperature) were measured at the center stations of each lake. Light intensity was measured using a Li-Cor Quantum meter (model LI-185B). Daily light input of the lake during the ^{14}C incubation (see below) was recorded using a Li-Cor printing light integrator (Model LC 550 with a pyranometer sensor 4023). Temperature was measured using a YSI thermistor (Model 33).

Chemical features (conductivity, alkalinity, oxygen, pH, and nutrients) were determined from each depth. Conductivity was measured using a YSI meter (Model 33). The Winkler method was used for the measurements of dissolved oxygen. Alkalinity was measured using the titration method (0.02 N H_2SO_4 to an end point of pH 4.5). pH was measured using an Orion Model 407A pH meter. Nutrient concentrations (NO_3-N, NO_2-N, NH_4-N and PO_4-P) were determined by filtering (0.45 μm Whatman glass fiber filter (GF/F), pre-combusted at 500 ^{o}C for 1 hour) water samples and freezing the filtrates, which were later analyzed on a QuickChem Automated Ion Analyzer (Lachat Instruments). Nitrate (QuickChem Method No. 10-107-04-1-B), ammonia (QuickChem Method No. 10-107-06-1-F) and orthophosphate (QuickChem Method No. 10-115-01-1-B) were measured.

All physico-chemical parameters at Touson Lake were measured monthly from January, 1986, to October, 1986. Samplings at Cypress Pond were done monthly from March, 1986, to June 1986

Phytoplankton samples were collected monthly from surface to 5 m from Touson Lake and surface to 2 m from Cypress Pond using a Van Dorn sampler and preserved in Lugol's solution. Cell numbers and identification were done using a Zeiss IM inverted microscope at 400x and 1000x, respectively. Cell numbers were

Table 1. Physico-chemical parameters of Touson lake in 1986. Values express the mean of 0 and 1 m, and of 3 and 5 m.

Parameters	Depth	Jan. 24	Feb. 23	Mar. 28	May 9	Jun. 13	Jul. 15	Sep. 9	Oct.28
Light (mean extinction coefficient: n)	0-5 m	1.32	0.62	1.52	1.83	2.18	1.93	2.13	2.08
pH	0,1 m	6.6	nd	6.8	7.3	6.9	6.7	6.8	7.0
	3,5 m	6.6	nd	6.5	6.7	6.6	6.4	6.3	6.4
O_2 (% saturation)	0,1 m	78.4	120.9	138.4	147.0	113.4	95.9	107.4	27.4
	3,5 m	70.4	60.4	23.3	38.3	8.3	2.1	nd	14.0
Alkalinity (mg/l as $CaCO_3$)	0,1 m	27.7	28.0	23.0	29.5	27.0	25.0	25.0	39.7
	3,5 m	28.2	27.2	35.0	59.0	70.5	48.1	76.0[*3]	38.2
Conductivity (μmhos/cm)	0,1 m	nd	77	83	78	57	55	65[*0]	98
	3,5 m	nd	79	97	101	108	78	150[*4]	99
PO_4-P (μg/l)	0,1 m	19.9	26.6	37.2	20.9	6.5	9.7[*1]	18.2[*1]	nd
	3,5 m	19.8[*5]	36.0	35.7	38.0	5.9[*3]	13.2	24.0	nd
NH_4-N (μg/l)	0,1 m	114.4	23.1	18.1	40.2	45.9	15.8[*1]	65.7[*1]	nd
	3,5 m	102.2[*5]	154.0	298.5	723	31.6[*3]	86.3	92.2	nd
NO_3-N (μg/l)	0,1 m	355.9	341.9	21.6	3.8	2.9	2.4[*1]	2.9	nd
	3,5 m	301.0[*5]	323.9	59.6	3.3	<1.0[*3]	3.7	3.4[*4]	nd

*0: 0 m, *1: 1 m, *3: 3 m, *4: 4 m, *5: 5 m, nd: not determined.

Table 2. Physico-chemical parameters of Cypress Pond in 1986. Values are means of 0, 1, and 2 m.

Parameters	Jan. 31	Mar. 3	Apr. 4	May 16	Jun. 15
light (mean extinction coefficient: n)	0.53	0.61	0.73	1.32	1.21
pH	6.5	6.9	7.1	6.6	6.3
O_2 (% saturation)	91.4	92.7	128.2	69.0	21.9
Alkalinity (mg/l as $CaCO_3$)	23.4	23.4	27	32.9	45.4
Conductivity (μmhos/cm)	nd	990	800	900	658
PO_4-P (μg/l)	4.7	7.7	9.1	15.7	25.5
NH_4-N (μg/l)	54.6	53.0	28.3	35.6	34.2
NO_3-N (μg/l)	9.0	5.8	4.5	3.1	2.2

nd: not determined.

counted from at least 25 fields at 400x from all of the samples collected. Monthly percent abundance of major groups of algae were calculated based on mean numbers of whole water column phytoplankton numbers.

Planktonic primary productivity was measured by the incubation of lake water in one dark and two light bottles with a known amount of $NaH^{14}CO_3$ (3-5 µCi/ml) in depths of 0, 1, 2, 3, 4 m at Touson Lake and 0, .5, 1, 2 m at Cypress Pond. ^{14}C incubations were done on the same dates when physico-chemical parameters were measured. After a 3-4 hour incubation period, all bottles were immediately placed in a dark chamber and brought to the laboratory. 50 ml of samples were filtered through a 0.45 µm cellulose acetate filter (Millipore)®. The filter was dried and combusted using a Packard Oxidizer (Model 305). $^{14}CO_2$ was trapped in scintillation cocktails (Carbo-Sorb, Permaflour, Packard Inc.) and analyzed by a Beckman liquid scintillation counter (Model LS3801). A Li-Cor light integrator was located in an open field near the lake. Calculations were done using the methods described in (10).

Spatial distribution of primary production of two oxbow lakes was measured at 5-6 sites situated longitudinally (5 sites, 300-400 m apart at Touson Lake; 6 sites, 200 m apart at Cypress Pond). Vertical incubations of one dark and two light bottles were done at a depth of 1 m at both lakes from 10 a.m. to 2 p.m. Temperature, alkalinity, light penetration, and oxygen were also measured at each depth from each site.

RESULTS AND DISCUSSION

Physico-chemical parameters: 1986 was a relatively dry year, and no flooding occurred. Thus, water levels at both lakes were fairly stable. Water temperature at both lakes did not drop below 6 °C during the winter (Fig. 3). Strong stratification began in late March at Touson Lake and early April at Cypress Pond. Fall turnover at Touson Lake occurs in late September annually (4). Due to the shallow depth, onset of stratification at Cypress Pond was much slower compared to Touson Lake. During the summer, Touson Lake was well stratified with a thermocline around 3.5 m, with surface temperatures of 28-30 °C and bottom temperatures of 13-17 °C. Seasonal patterns of temperature stratification of these lakes belong to the warm, monomictic type (9). Oxbow lakes of the Mississippi River at the same latitude also exhibit similar thermal cycles found at Touson Lake (1, 6).

Ranges of pH at both lakes were similar (6.3-7.5) (Tables 1 and 2). The increase of pH during the spring at both sites seemed to be related to increased phytoplankton activity. Relatively high levels of oxygen concentration were found in the epilimnion of Touson Lake from late February to mid-June. Alkalinity and conductivity at both sites showed a similar seasonal pattern. While a strong hypolimnetic increase during the stratified period was found at Touson Lake, Cypress Pond showed a slight increase at 2 m in May and June.

All nutrients (PO_4-P, NH_4-N, and NO_3-N) at Cypress Pond were consistantly lower than Touson Lake during the study period. Ammonia and nitrate at Touson Lake showed a strong seasonality. Relatively high concentrations occurred in winter followed by decrease in the epilimnion in March. During the summer, epilimnetic

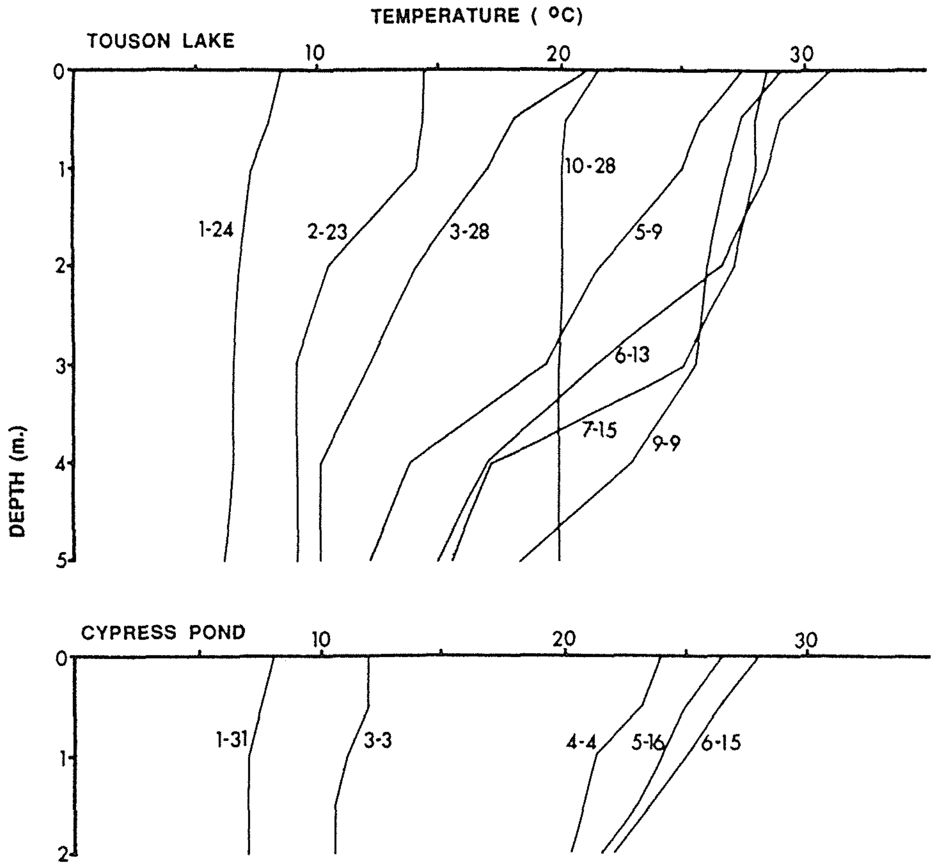


Fig. 3. Changes of temperature at Touson Lake and Cypress Pond in 1986.

concentrations of ammonia and nitrate were at the detection limits. Ammonia concentrations in the anoxic hypolimnion of Touson Lake increased during the summer and the fall turnover concentrations became uniform thoughout the water column.

Phytoplankton succession: Green algae were most abundant in both lakes during the study period (Fig. 4). As fall progressed, blue-green algae replaced the green algae. However, in Cypress Pond, blue-green algae comprised a small portion (<7 %) of total abundance and euglenoids comprised a substantial portion (8-40 %). In early winter, with an increase of cryptomonads and a decrease of blue-green algae, the abundances of major algal groups at Touson Lake were more equal. With the exception of early spring at Cypress Pond, diatoms were seldom a dominant group at both lakes.

Phytoplanktonic primary productivity: Mean daily primary productivity values of phytoplankton at Touson Lake and Cypress Pond were 258 (range: 43 to 549, n=6) and 88.5 mgC/m^2/ day (range: 16 to 256, n=4), respectively (Fig. 5). Highest production occurred in May and July at Touson Lake and June at Cypress Pond. Most of the production was restricted to the upper 2 m at Touson Lake; less than 10% of total daily production occurred below a depth of 3 m. In the shallower Cypress Pond, highest production was consistantly observed at a depth of 0.5 m. Due to the

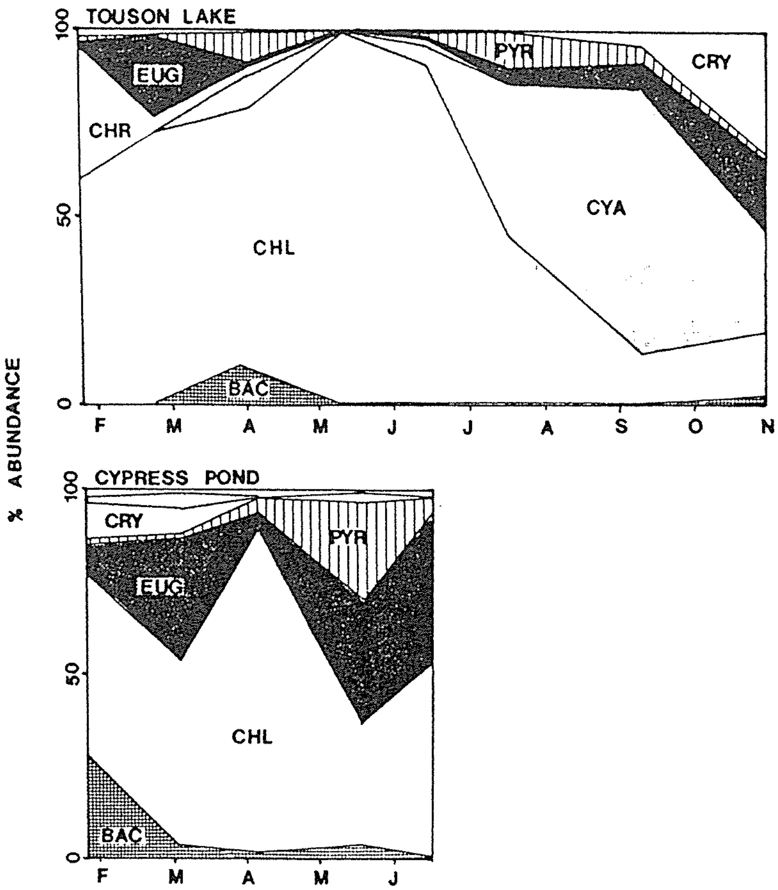


Fig. 4. Seasonal changes in algal communities in percent abundance of Touson Lake and Cypress Pond (CYA: Cyanophyta, CHL: Chlorophyta, EUG: Euglenophyta, BAC: Bacillariophyta, CHR: Chrysophyta, CRY: Cryptophyta, PYR: Pyrrophyta).

relatively higher light transmission, light inhibition of carbon fixation at the surface was observed throughout the 4 incubations.

Phytoplanktonic primary productivities at Touson Lake and Cypress Pond were generally low and in the oligotrophic and mesotrophic lake ranges as summarized by Wetzel (9) (oligotrophic: 50-300, mesotrophic: 250-1000 mgC/m^2/day). However, total primary productivity was likely higher in Cypress Pond because of extensive development of aquatic macrophytes and associated periphyton. Phytoplankton seemed to make a more important contribution to primary production in Touson Lake than Cypress Pond, probably because it is deeper and more turbid than Cypress Pond and has less aquatic macrophyte development. This pattern of productivity in Touson Lake may be representative of many Black Warrior River oxbow lakes, since oxbow lakes in this region appear to share similar morphometric and general limnological characteristics with Touson Lake (i.e., relatively deep: > 4m, and very turbid: average Secchi disc transparency: <1m, and few submersed macrophytes). Although they are deeper and bigger than Touson Lake, many Mississippi River oxbow lakes also show similar limnological characteristics with Touson Lake (i.e., turbid and scarce distribution of submersed

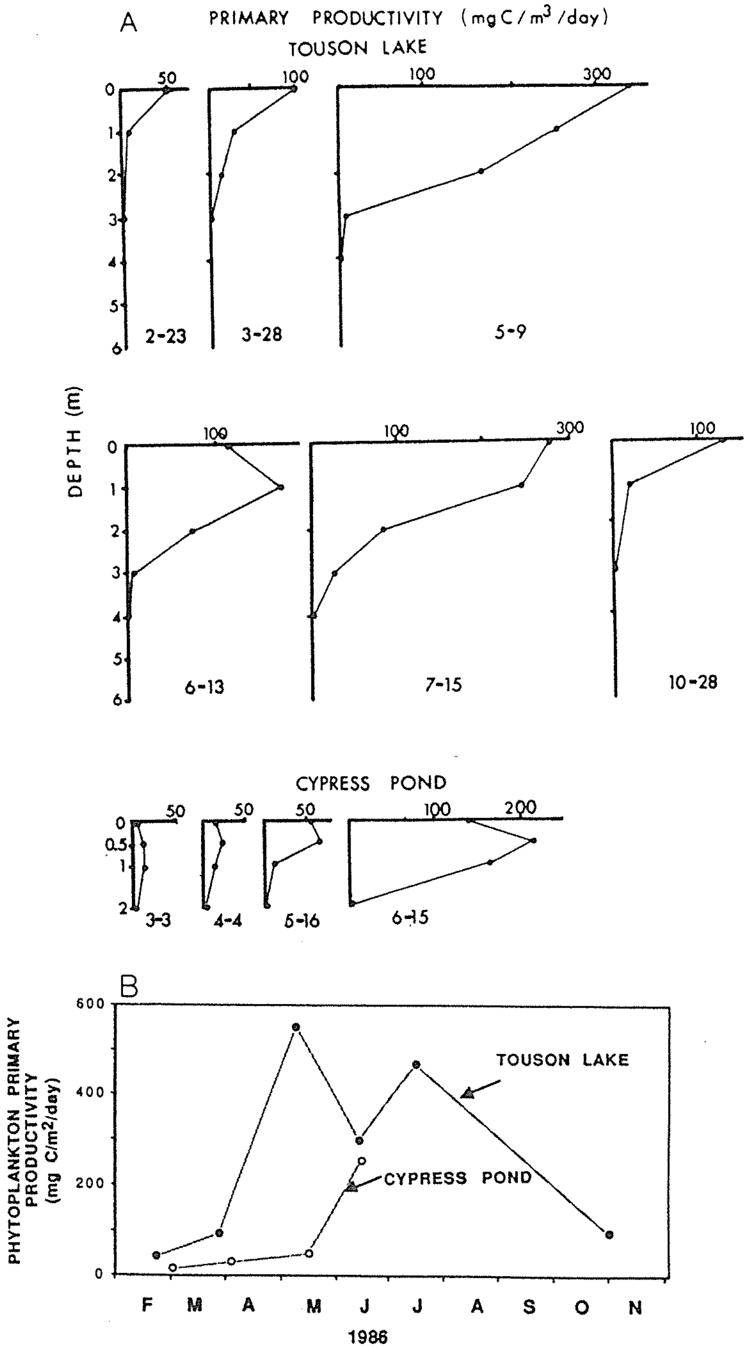


Fig. 5. A) Vertical distribution of phytoplankton primary productivity at Touson Lake and Cypress Pond (mgC/m^3/day). B) Integrated areal phytoplanktonic productivity of Touson Lake and Cypress Pond (mgC/m^2/day).

and aquatic plant development in determining physico- chemical and metabolic properties of floodplain lakes.

aqutic macrophytes). Thus, similar patterns of priamary productivity may occur in many Mississippi River oxbow lakes.

Spatial distribution of phytoplanktonic productivity: Longitudinal heterogeniety of phytoplankton primary productivity at both sites showed some variability (Touson Lake 19.8 $\pm$ 6.6, n=5, 16.5 + 19.1 mgC/m3/h, n=6) (Fig. 6). Coefficients of variation (CV) of primary productivities of Touson Lake and Cypress Pond were 33.0 and 115.7%, respectively. Underwater light environments strongly affected the the primary productivity at both sites. Submersed and floating aquatic macrophytes in Cypress Pond directly affected the primary productivity and thus variability was very high. However, at Touson Lake, primary productivity was less variable. In the shallow regions (such as site 3 at Touson Lake), light transmission was consistantly low due to the interactions between the sediment and water column, while other physico-chemical parameters (temperature, pH, alkalinity, and conductivity) were not noticeably different.

Although Cypress Pond and Touson Lake shared some similar characteristics, other features were somewhat different. For example, lakewater nutrients were lower, light penetration higher, and phytoplanktonic productivity generally lower in Cypress Pond compared to Touson Lake. Although light penetration was typically higher, the internal shading from patches of submersed macrophytes was the probable cause of the more spatially variable phytoplanktonic productivity in Cypress Pond. These differences underscore the importance of lake morphometry and aquatic plant development in determining physico-chemical and metabolic properties of floodplain lakes.

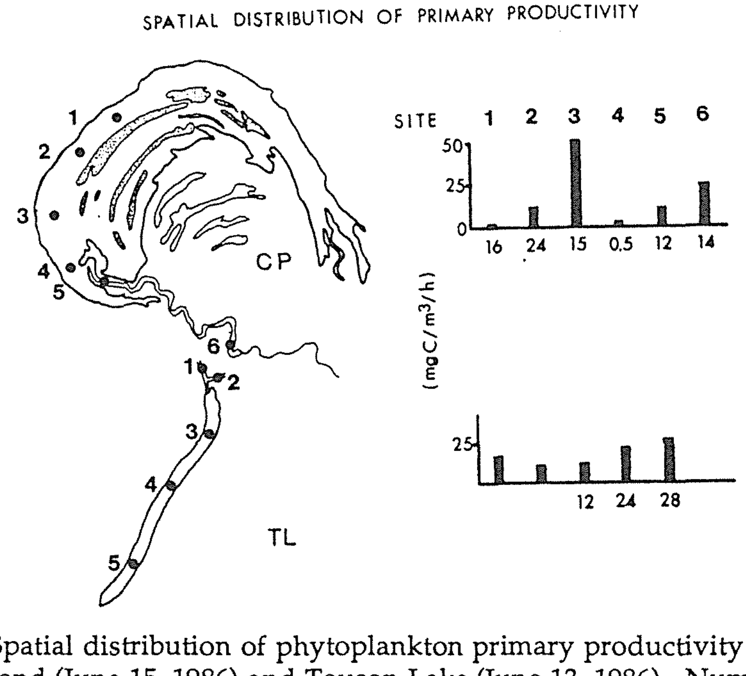


Fig. 6. Spatial distribution of phytoplankton primary productivity (mgC/m^3/h) at Cypress Pond (June 15, 1986) and Touson Lake (June 13, 1986). Numbers beneath the bars of each graph indicate percent light transmission at a depth of 1 m.

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